THE SIGNIFICANCE OF CREATING A NETWORK DIAGRAM (CPM METHOD) IN THE PRODUCTION OF WHEAT[1]

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Abstract

This work primarily describes organisational and economic conditions in the production of wheat, emphasizing, at the same time, the necessity to procure with farm machinery. Also, the development of methods in network planning techniques (CPM and PERT method) is analyzed and the concept, factors and methodology of network planning, as well as the rules for drawing a network diagram are defined. If we include mathematical model into the network model, we get detailed information on terms for carrying out an operation and how long the production will last. The aim of the analysis is to explain the significance of creating a network diagram (CPM METHOD) for the production of wheat on 20 ha. Defining technology interdependence charts and lists of activities completes the process of creating a network diagram. Finally, the work contains tabular presentation of an analysis of costs of machinery services in the production of wheat. However, because of frequent price oscillations of oil derivatives, the costs of diesel fuel were singled out from the costs of machinery service.

Key words: *wheat, technological chart, network diagram, CPM method.*

Introduction

In the conditions when there is a growing labour division and specialization, planning in agricultural companies has become more complex. Agricultural companies begin to create plans with various aims. In the case of wheat production technological chart is being created which

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includes working operations during vegetation for the period from planting to harvest and which defines how long each individual activity lasts. In plans of this kind there is the highest possible level of predictibility because it is exactly ordered who should do what and when in order to accomplish scheduled task.

Network diagram is created in order to make graphical representation of working operations (based on a scheduled order of operations in technological chart). The most simple technique of creating a network diagram is a *technique of network planning. Network planning technique enables planning, coordination and control of complex processes where it is necessary to coordinate large number of jobs in order to accomplish the whole working task in a certain time limit, with minimum burdening of those that take part in realization.*Two network planning techniques are significant - CPM method *(Critical Path Method)* and PERT method *(Program Evaluation and Review Technique)*.

This work presents CPM method and practical application during wheat production on the surface area of 20 ha. Working operations are presented by technological chart and the duration of operations is determined in days. To determine the number of days required for the performance of activities per hectare, used norms are shown in the price list of mechanical services *(ZSV, 2011)*.

Then, the list of interdependance among activities is created which shows which operations must be carried out after the previous are finished and which can be carried out simultaneously. Also, creating is network diagram using CPM method, which shows critical path (determines the duration of a project) and time reserves (activities that are not on critical path and their duration is less than maximum allowed duration). Tables follow network diagram where are detailed analysis of time and time reserves. Finally, there is also a tabular presentation of costs of machinery services (without diesel fuel costs) for the entire surface area *(Price list, 2011)*.

Organisational and economic conditions in the production of wheat

Crop production requires the use of self-propelled, and driving the tractor trailers and vehicles. Since the machines are essential tractors, while for transport, except unit that makes the tractor and trailer, can be used truck, van, etc. Implements also not be a constraint in the production process, so that depending on the needs of use: ploughs (two-furrow and three-furrow), mounted disc harrow, draw seedbed tiller, mounted atomizer, seeders (narrow-row and wide-row drill), trailers (capacity per 7 hectares), etc. For the purposes of the harvesting in using are harvesters *(Ristić, 2010.).*

Rational organisation in the production of wheat requires an excellent knowledge of organisational and economic conditions and an excellent knowledge of natural resources. These conditions restrict final result in production by affecting income and the costs of production.

Procurement with farm machinery represents one of significant organisational and economic conditions which help in achievement of higher incomes, higher productivity, to reduce the costs of production and increase competitiveness of this type of production. Beside soil working machines, machines for fertilization and plant protection, it is impossible to imagine wheat production without special sowing machines, combines - harvesting machines and straw packing machines. The range and structure in using machinery in the production depend on the type of production and the system for growing plants; they also depend on crops, weather and soil conditions, on the level of production organisation and organisation of work and on the level of production intensity. Average return from wheat depends on various factors, for example on the quality of the applied agrotechnique, additional plant nutrition, crop protection, the choice of plant type, weather conditions during vegetation. In average, return from wheat is 5,5-6,5 t/ha. An average return from ground biomass (straw and chaff) is 35-45% of an average return, in other words an average return is 2-3 t/ha, depending on the sort *(Munćan, Živković, 2006).*

Development of basic methods in network planning techniques

There are two important methods that appeared in the world:

1. *Critical Path Method - CPM*
2. *Program Evaluation and Review Technique - PERT method*

Critical Path Method was created in 1956 because of the need to develop planning system for chemical industry, but it was meant to serve especially for revision planning and work on automatic plant maintenance. At the beginning, research pointed to the fact that the problem could be solved only by applying mathematical methods and using electronic adding machines. At the beginning of 1957 first written studies were published related to planning by critical path method and at the end of the same year it was started with method application. Satisfactory results were achieved and therefore the method was expanded by new tasks (remont and chemical plant maintenance). Since 1959 many scientific works about critical path method were published by various authors ad especially by James E. Kelley Jr. and Morgan R. Walker Jr. Both mentioned authors actively participated in the research, and the result was that the method was expanded. Critical Path Method also appears under the name CPS (Critical Path Scheduling) and CPPS (Critical Path Planning and Scheduling) in practice, but among these methods there is no essential difference *(Ceranić, 2007).* Analysis of time in application of CPM method has only one estimation of time and it is indicated as estimated or standardized time *(Jelisavčić, 2010).*

PERT method appeared as an result of a task aiming to develop system of planning, informing and managing very complex projects with numerous uncertainties. In an earlier phase of development (1956) on a rocket programme POLARIS (ballistic missiles and nuclear submarines) the conclusion was made that all conventional leading systems represent an inefficient system for programme observation. Newly created method was named PERT method and first published studies appeared in 1958. Success achieved by the navy became interesting for other branches of the american army, so they intensively started with network planning, especially in the air force. At the beginning, PERT method was used only by bureaus or institutions that were dealing with military orders. In time, instructions for an application of PERT method in companies were created, so this method started to be used in other social activities, too. This method was completed by including an analysis related to project costs. The Ministry of Navy organized PERT method training courses in order to be available to citizens and movies were also made about coordinated planning. Soon the application of network planning was spread to Europe, since the american institutions started to use this method in their branch offices in Europe and further *(Ceranić, 2007).* An analysis of time includes three activities duration estimates in an application of this method *(Jelisavčić, 2010):*

- *optimistic* - minimum activity duration;
- *possible* - period in which would activities finish under normal conditions;
- *pesimistic* - the longest duration of activities under unfavorable conditions.

The concept, factors and methodology of network planning technique

At the same time with the development of science, technique and technology, scientific methods of planning were developed. Technification revealed that rational project planning cannot give precise solutions. In order to avoid mistakes in planning scientific methods started to be developed and the most significant was *network planning technique (Jelisavčić, 2010)*. Network planning technique enables sufficiently precise review of the whole work realization, logical development review and the review of mutual dependance between the parts of the process and the process itself. *In a word*, **network planning technique enables** *planning, coordination and control in complex processes where it is necessary to coordinate large number of partial activities in order to carry out a full business plan in a certain time limit, with minimum burdening of those that take part in realization.* Network diagram is created using activities (arrows) and events (circles) and represents graphical presentation of the observed project realization. It is a mathematical model of a project by which bussiness plan results could be analized and explained. Network diagram (model) of a project represents the sequence of activities. Every event is marked by a number. The first event is marked by number one and the last one with n. If we mark the first one with i and the last one with j, then the activity can be marked with the symbol A_{ij}. The mark explains with which event the activity starts and with which ends.

Basic **factors** of network planning technique are: project, activity and event *(Jelisavčić, 2010*). *Project* is a set of measures (economic, organizational and technical) whose aim is to realize certain aim. Project requires engagement, organisation and resource management, and the essence of resource management includes organisation, planning, projecting, realization and control of assigned processes. *Therefore, it is necessary to determine the sequence of operations and undertakings which will achieve final results, or in other words realize the project, followed by constant striving toward final aim.* So, for example, the project is: presentation of a new product, scientific research topic, growing perennial plant nurseries, an investment in the construction of agricultural buildings, an investment in the introduction of amelioration systems and other. *Activity* is an integral part of a project which is a complex whole. Activities are individual technological tasks or jobs whose logical connection makes the observed project and whose realization requires certain measures and certain time. Every activity must be limited by the earliest beginning and the latest end. Activities are represented by arrows whose length is not determined by action duration. Except activities that require certain time and measures there are also so-called *fictitious activities* that don't require time and measures and which enable realistic review of connection among certain activities within the project and are represented by broken arrows. *Event* is an observed time interval at which certain activity starts or ends (one, several or the whole project) and it doesn't have time dimension. Events are graphically represented by a circle in which necessary data are written. Event is, for example: the beginning of preparation for sowing, harvest, gathering, the end of sowing, harvest, gathering and other.

The special advantage of network planning is the possibility to separate **methodological wholes** completely *(Jelisavčić, 2010):*

1. *structure analysis* - analizes the sequence in technology, relations in activities within the project and creation of network diagram (graphical representation of project realization).
2. *time analysis* - includes determination of time needed for the realization of certain activities and for the whole project; it is essential to determine "critical path" of the project;
3. *costs analysis* - determination of costs for certain activities and for the whole project, as well as finding optimum relation between time and costs in realization (of activities and of project);
4. *resources analysis* - includes material, equipment and working labour planning (*Glišović*).

Beside mentioned network planning advantages, there are also *(Glišović)*:

- *the creation of network plan requires previous detailed project analysis, which results in better understanding of an undertaking;*
- *the saving of time and resources;*
- *realization control;*
- *calculation of time reserves for analysis and levelling of resources;*
- *personnel and resources can be distributed in advance.*

Practical application of CPM method in the construction of network diagram in the production of wheat

The starting point for the development of a network diagram work processes are presented in the form of maps and lists of technological activities. The obtained values allow for the creation of network diagrams. Formed a network diagram following two tables - analysis time and analysis time reserves. Tabular view indicators of time analysis provides information about whether it can be and how much time units to delay the start or the end of a work activity. After analyzing the access time to the analysis time reserves, and indicators are used to determine the specific activities that must begin at their earliest beginnings that have been completed in their latest endings. Activities whose time reserves equal to zero indicating that there is no freedom in a time of their execution, ie. must be made at fixed times. Activity with such properties is a critical activity.

Simultaneous creating of techological charts compiled and technological documentations which accompanying the technological process. Technological documentations has a basic task to determine the order and the way of technological operations in the technological process. Technological documentations establishing procedures, and the types and quantities of materials used, types of tools, the tools and how to work with them, work operations, etc. As technology documentations used by different types and forms of documentation and the most commonly used is technological map *(Lajović, Vulić, 2010).*

Technological chart, as seen in columns, include: the working process, activity tags (alphabetical order), time of the execution, planning number of working days to perform, the composition of the working group (workers and machines), unit of issue, daily output, the total workload and the total number of days in a given activity. In order to determine the required number of days in wheat production, technological chart must contain the above-mentioned technical - technological and organizational elements. According *Dimitrijević, Ceranić (2011)* technological chart represents a plan under which existing organizational - economic criteria define the level of intensity of production, the rational behavior of all actors in the coordination of production and implementation of a production process. Depending on the type of soil, the previous culture and technology selection, the choice of certain cultural practices and daily performance and machine work during the performing certain operations. Implementation of the planned work processes in optimal agro-technical terms helps to reduce the actual cost of production compared to the planned.

The following table *(table 1)* contains a sequence of technological operations and cropping periods in the production of wheat on an area of 20 ha.

Table 1. *Technological chart of wheat production*

No.	The working process	Activity tags	During the execution	Number of working days for the execution	Composition of the working group		Unit of issue	Daily output	Overall work	For all the work to date
					Workers	Machine				
1.	Subsoiling	A	VII	2	1	1	ha	4,8	20	4
2.	Shallow ploughing to 15 cm (fallowing)	B	VIII	4	1	1	ha	3	20	7
3.	Fertilization (NPK, 0.4 t / ha)	C	IX	2	1	1	ha	5,4	20	4
4.	Ploughing (40 cm)	D	IX	13	1	1	ha	0,9	20	22
5.	Preparation Sowing (up to 4 m)	E	X	3	1	1	ha	4,2	20	5
6.	Sowing (0.3 t / ha)	F	X	5	1	1	ha	2,4	20	8
7.	Top dressing I	G	II	2	1	1	ha	5	20	4
8.	Top dressing II	H	III	2	1	1	ha	5	20	4
9.	Weed contrtol	I	IV	2	1	1	ha	8,4	20	3
10.	Harvesting	J	VII	4	1	1	ha	3	20	7

Source: *The author's view sequence of technological operations.*

The number of working days intended for the realization of operations is calculated using standard indexes which are published (*ZSV, 2011)*. In the original document daily standards for the performance of all individual operations are presented (in ha), which are in accordance with the needs of sowing wheat on 20 ha. Therefore, for example, for shallow plowing up to 15 cm of depth daily standard is 5 ha, which means that for 20 ha of surface area planted with wheat 4 days are needed. The choice of certain agrotechnical measures, as well as the daily output of human and machinery work during certain operations differ depending on the land type, what was previosly planted on it and the technology. Realized daily output per hectare is 30 - 40% less than the standardized one. The losses include: machinary maintenance, rest, time for preparing and finishing, travelling to the place of work and back, time for turn and supplying per hectare (Milić *et al, 2001*). Therefore, the number of days necessary for the realization of whole work is larger than standardized.

Base on the technological chart the list of activities is being created which determines the sequence of operations and the possibility to perfrm them at the same time. Accordingly, the list of activities shows the correlation between activities ie. relationship observed and the previous activity. A list of activities in the production of wheat is shown in the following table *(table 2).*

Table 2. *List of activities in the production of wheat*

Mutual relations activities		**Considered activity**									
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Previous activities	A		+								
	B			+	+	+					
	C						+	+			
	D							+			
	E								+		
	F										+
	G									+	
	H									+	
	I										+
	J										

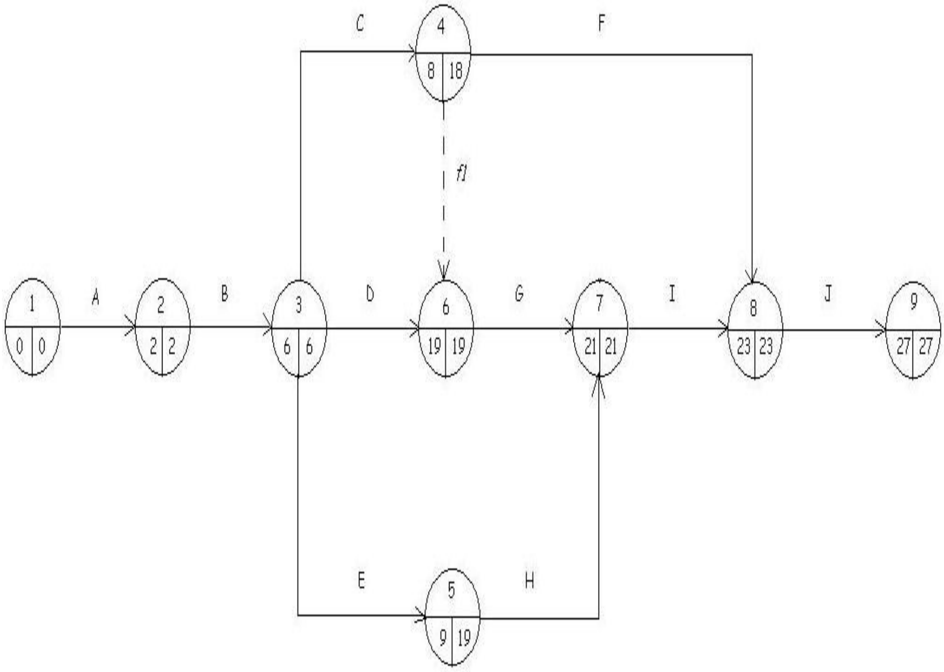
Source: *Table 1.*

Activities marked alphabetically (A - J) symbolize the interdependence of work processes. For example. work activity B (shallow ploughing to 15 cm - fallowing) begins after the activity A (subsoiling) and so on.

When interdependant activities are determined, we created a network diagram using CPM method. On network diagram we are drawn knots and activities. Marks of activity are taken from technological chart, activities are marked in alphabetical order (A-J), positioned above the arrow in the diagram with one fictitious activity (f1), which is indicated by dashed lines represent the number of days to perform specific work process. Numbering used is growing event (1 - 9), which shall be entered in circles of diagram. On the diagram we can see the critical path and determine the total duration of all activities in the production of wheat.

The following graph (*graph. 1*) is a network diagram (CPM method) in wheat production.

Graph. 1. *Network diagram (using CPM method) in production of wheat*



Source: *Table 1 and 2.*

Critical path includes those activities which don't have free time reserves and which contain critical activities (time reserves are equal zero), so therefore must be performed in the latest time limit. Duration of some activities determines the duration of the whole project. In case when it comes to changes in duration of any activity on a critical path, it immediately affects the duration of the whole project.

In this example, *27 days* are needed for the implementation process in production of wheat on an area of 20 ha. *Critical path includes activities:* 1-2-3-6-7-8-9. Other activities (4 – ploughing, 5 - preparation sowing) are the activities with *time reserve.* Their dislocation of critical activities affect the shortening of the duration of critical activities, and that means a potential cost savings in the production of wheat.

Prepared network diagram accompanying two tables - analysis time and time reserves *(table 3 and 4).*

Basic parameters within time analysis are *(Ceranić, 2007):*

- *the earliest beginning of an activity* E_{ij}^{p}
- *the earliest end of an activity* E_{ij}^{z}, which is calculated: $E_{ij}^{z} = E_{ij}^{p} + t_{ij}$
- *the latest beginning of an activity* L_{ij}^{p}, which is calculated: $L_{ij}^{p} = L_{ij}^{z} - t_{ij}$
- *the latest end of an activity* L_{ij}^{z}.

Between the earliest beginning and the latest end of an activity there is an available time period within which the observed activity must be finished. Therefore, the following relation must be realized: $t_j^1 - t_i^0 \geq t_{ij}$.

Table 3 presents the analysis time in the production of wheat.

Table 3. *Analysis time in the production of wheat*

Connection between events i - j	Duration of activity t_{ij}	Earliest time		Latest time		Maximum time to perform activities $L_{ij}^{z} - E_{ij}^{p}$
		Begining E_{ij}^{p}	Ending E_{ij}^{z}	Begining L_{ij}^{p}	Ending L_{ij}^{z}	
1-2	2	0	2	0	2	2
2-3	4	2	6	2	6	4
3-4	2	6	8	16	18	12
3-5	3	6	9	16	19	13
3-6	13	6	19	6	19	13
4-6	0	8	8	19	19	11
4-8	5	8	13	18	23	15
5-7	2	9	11	19	21	12
6-7	2	19	21	19	21	2
7-8	2	21	23	21	23	2
8-9	4	23	27	23	27	4

Source: *Graph. 1.*

Each activity whose duration is less than its maximum allowed duration has certain time reserve and time reserves are present only at those activities which are not on the critical path (4-5). In the example of wheat production activity duration is shorter than the maximum time in activities with the marks C (fertilization, the connection between the events 3-4), E (preparation sowing - the connection between the events 3-5), F (sowing - the connection between the events 4-8) and H (top dressing II - the connection between the events 5-7). Consequently, the number of days to remaining in the operations of these can be compensated for the remaining operations (which are on the critical path) if it is needed due to a possible excess of the standard time.

After tabulation time analysis approaches to the analysis of time reserves. It is primarily necessary to analize five types of time reserves, where four are related to activities and the fifth to knots *(Ceranić, 2007):*

1. *total time reserve* (T_{ij}), which is calculated: $T_{ij} = t_j^1 - t_i^0 - t_{ij} \geq 0$;
2. *free time reserve* (F_{ij}), which is calculated: $F_{ij} = t_j^0 - t_i^0 - t_{ij} \geq 0$;
3. *independent time reserve* (N_{ij}), which is calculated:
$$N_{ij} = t_j^0 - t_i^1 - t_{ij} \gtreqless 0; \quad N_{ij} \leq T_{ij};$$
4. *dependent time reserve* (Z_{ij}), which is calculated: $Z_{ij} = t_j^1 - t_i^1 - t_{ij} \geq 0$;
5. *critical time reserve* (K_{ij}), which is calculated: $K_{ij} = t_i^1 - t_j^0$.

Accordingly defined patterns, approach to calculating time reserves, wich values are given in *table 4.*

Table 4. *Analysis of time reserves in wheat production*

Connection between events	Duration of activity	t_i^0	t_j^0	t_i^1	t_j^1	T_{ij}	F_{ij}	N_{ij}	Z_{ij}	K_{ij}
1-2	2	0	2	0	2	0	0	0	0	0
2-3	4	2	6	2	6	0	0	0	0	0
3-4	2	6	8	6	18	10	0	0	10	0
3-5	3	6	9	6	19	10	0	0	10	0
3-6	13	6	19	6	19	0	0	0	0	0
4-6	0	8	19	18	19	11	11	1	1	10
4-8	5	8	23	18	23	10	10	0	0	0
5-7	2	9	21	19	21	10	10	0	0	10
6-7	2	19	21	19	21	0	0	0	0	0
7-8	2	21	23	21	23	0	0	0	0	0
8-9	4	23	27	23	27	0	0	0	0	0

Source: *Graph. 1.*

Calculated time the event occurred, and based on them, defined time reserves are used to determine the activities that must begin at earliest beginnings to be completed in his the latest endings.

These are activities whose time reserves are equal to zero, meaning that there is no freedom in a time of their implementation, must be carried out in clearly defined times. Mentioned parameters are explained in the example of subsoiling operation (connections between events 1-2):

- total time reserve with a value of 0 indicates that it can not move the deadline of the earliest possible beginning of the activity and can not be extended time duration;
- free time reserve with a value of 0 indicates that it can not move the deadline of the earliest possible beginning of the activity and can not be extended time duration, because it endangers the earliest possible beginning of all following activities;
- independent time reserve with a value of 0 indicates that it can not move the deadline of the earliest possible beginning of the activity and can not be extended time duration; can be used positive and negative values, but the only positive are used to extend the duration or shift the earliest possible date that beginning activities;
- dependent time reserve with a value of 0 indicates that it can not move the deadline of the earliest possible beginning of the activity, if any previous activities are completed no later than time allowed;
- critical time reserve with a value of 0 indicates that the appropriate knot is on the critical path.

Time analysis and time reserves analysis represent the second phase in network planning – time analysis. The third phase is the most complicated - the analysis of costs. This phase determines the factors upon which the realization of the whole project depends, and at the same time the relation between resources and time is being researched.

This phase in network planning is performed separately. This phase determines daily costs of machinery work (per hectare) in relation to certain operations in the production of wheat and based on the price list for 2011 *(table 5).* Because of frequent oscillations in the price of fuel derivatives, the costs of diesel fuel were singled out from the costs of machinery service.

Table 5. *Costs of mechanical services (2011)*

No.	The working process	Unit of issue	Price (RSD/ha)	Costs for the 20 ha (RSD)
1.	Subsoiling	ha	4.450	89.000
2.	Shallow ploughing to 15 cm (fallowing)	ha	3.040	60.800
3.	Fertilization (NPK, 0.4 t / ha)	ha	960	19.200
4.	Ploughing (40 cm)	ha	4.820	96.400
5.	Preparation Sowing (up to 4 m)	ha	1.200	24.000
6.	Sowing (0.3 t / ha)	ha	1.300	26.000
7.	Top dressing I	ha	1.900	38.000
8.	Top dressing II	ha	1.900	38.000
9.	Weed contrtol	ha	2.440	48.800
10	Harvesting	ha	7.100	142.000
Total			29.110	582.200

Source: *Zadružni savez Vojvodine (2011): Cenovnik mašinskih usluga u poljoprivredi, Novi Sad.*

Generally, total costs of machinery service for the production of wheat on the surface area of 20 ha are 582.200 RSD, but the costs of diesel fuel are not included *(table 5)*. Total costs of machinery services are calculated by multiplying the quantity of fuel used in each operation with retail price of fuel actual at the moment of calculation. For calculating the costs of machinery services per cadastre acre the price from the price list (din/unit of issue) should be multiplied by coefficient 0,5754.

Conclusion

The significance of creating a technological chart is complex, through which it is emphasized: determination of the numbers of days needed for the realization of each operation, facilitated coordination of participants' activity, prevention from greater mistakes in management, determines the level of management successfulness and similar. The list of activities additionally facilitates the creation of network diagram and points out an interdependance among activities and possibilities to perform several activities at the same time, which results in shortened costs in the production of wheat. The significance of network diagram application is increasing considering the fact that it saves time and material resources and enables control under the realization of the whole process. Based on the network diagram facilitated the define the disposition human and material resources necessary to carry out the project.

Generally, the significance of network diagram application in the production of wheat enables rational use of all available resources because the sequence of activities makes it impossible to double time and costs, in other words project leader can successfully change the duration of individual working process realization, but limited by time reserves, which results in less uncertainty regarding the realization of the project. Network diagram defined *27 days* for the implementation process in production of wheat on an area of 20 ha. Dislocation time, at the activities with time reserve (4 – ploughing, 5 - preparation sowing), on critical activities affect the shortening of the duration of, and that means a potential cost savings in the production of wheat.

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